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Surgical Instrument Restraint in Weightlessness

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Abstract

Performing a surgical procedure during spaceflight will become more likely with longer duration missions in the near future. Minimal surgical capability has been present on previous missions as the definitive medical care time was short and the likelihood of surgical events too low to justify surgical hardware availability. Early demonstrations of surgical procedures in the weightlessness of parabolic flight indicated the need for careful logistical planning and restraint of surgical hardware. The consideration of human ergonomics also has more impact in weightlessness than in the conventional 1-g environment. Three methods of surgical instrument restraint – a Minor Surgical Kit (MSK), a Surgical Restraint Scrub Suit (SRSS), and a Surgical Tray (ST) were evaluated in parabolic flight surgical procedures. The Minor Surgical Kit was easily stored, easily deployed, and demonstrated the best ability to facilitate a surgical procedure in weightlessness. Important factors in this surgical restraint system include excellent organization of supplies, ability to maintain sterility, accessibility while providing secure restraint, ability to dispose of sharp items and biological trash, and ergonomical efficiency.

Medical care systems for previous manned spaceflights have had minimal or no capabilities for the performance of on-orbit surgical procedures. These missions were designed to have short times to definitive medical care, crew medical officers had limited surgical capabilities and minimal surgical hardware was present in-flight. Serious surgical problems were correctly predicted to be rare events (1) and were planned to be managed by mission abort and immediate medical evacuation. With the advent of longer duration spaceflights, a continuous manned presence on the International Space Station (ISS), and future requirements for missions such as Lunar Base and the Mars Expedition, the surgical capabilities of on board medical care systems will need to become more important (2). Studies of environments that are analogous to spaceflight (especially Antarctica research stations and U.S. Navy submarines) have shown that injuries and surgical events are the most common indication for medical evacuation in these programs (3,4).

The Mercury, Gemini and Apollo missions had essentially no surgical capabilities. Skylab was the first U.S. long duration flight and its crew had the ability to perform a minor surgical procedure under local anesthesia. A minor surgical kit was developed and flown on three missions but was never utilized. This kit had the majority of minor surgical supplies in one sterile package for one time use (5).

The Shuttle Orbiter Medical System (SOMS) for the Space Shuttle has surgical instruments available for minor procedures, such as laceration closure. The instruments are individually sterile wrapped and located in one package, the Surgical Supply Subpack (Figure I). This allows for maximum flexibility in accessing individual instruments without contaminating the entire surgical kit. The ISS has a definitive medical care time of only 6-24 hours and the medical system is oriented towards the stabilization and transport of critical injuries. The ISS Crew Health Care System (CHeCS) was designed with this consideration and there are no plans to support major surgery in flight. Minor surgical hardware

and capabilities are similar to the Shuttle (6). There is an Emergency Surgical Subpack (Figure II) located in the in the Advanced Life Support Pack and another Surgical Supply Subpack in the Ambulatory Medical Pack . The crew medical officer for both of these programs is not required to be an M.D. and receives only 20 (Shuttle) to 60 (ISS) hours of medical training. Future exploration missions will have longer definitive medical care times and will need to have a more surgically capable medical care system with more surgical hardware and more surgically experienced crew medical officers.

Many problems and surgical issues have been studied in the weightlessness of parabolic flight to determine the feasibility of performing a surgical procedure in flight. It has been found that if a well thought out system of restraint for the operator, patient, and all hardware (instruments, supplies and discarded trash) is rigidly practiced, then even complex procedures are not significantly more difficult to perform than in the 1-g environment. Control of bleeding was found not to be the major problem that it was first

speculated to be. Bleeding was found to be easy to control with local measures such as sponging and did not contaminate the cabin atmosphere. The predominance of surface tension forces in weightlessness causes blood to form large fluid domes that are not difficult to control instead of dispersing into the cabin atmosphere as previously expected. The restraint of all surgical instruments and supplies in a systematic manner was found to be critical for the ability to perform a procedure in weightlessness in a conventional, organized and efficient manner (7,8,9).

The purpose of this study was to determine the best methods of restraining surgical instruments and supplies in order to be able to perform a minor surgical procedure in weightlessness. Issues such as instrument and supply restraint, the disposal of trash, the safe securing of sharp items, organization of supplies, maintenance of sterile field and accessibility by the operator were examined.

Methods

Various surgical procedures (laceration closure, chest tube insertion, tracheostomy, peritoneal lavage, laparoscopy, and thorascopy) were performed under general anesthesia on a 50 kg porcine animal model in the weightlessness of parabolic flight. The Institutional Animal Care and Use Committee approved all study protocols. Animal care was according to NIH guidelines and all animals were euthanized at the end of each procedure. The NASA microgravity research KC-135 program was used to fly 16 parabolic flight missions with 40-60 parabolas in each mission. Each parabola gave approximately 30 seconds of 0-g weightlessness followed by a 2-g pullout.

Three methods of instrument/supply restraint and organization were examined and compared. One method was the use of a Minor Surgical Kit (MSK) that was deployed as a soft pack on the cabin wall or floor with Velcro attachments in close

proximity to the operative site. Another method involved the use of a Surgical Restraint Scrub Suit (SRSS) that was worn by the operating physician. This scrub suit was stored as a soft pack and was put on in a similar sterile technique fashion to an operating room scrub suit without contaminating the operating interface of the suit or the supplies restrained on the suit. The final method was a Surgical Tray (ST) which was organized similar to the MSK but mounted on a rigid surface which could be deployed in closer proximity to the actual operative site.

The Minor Surgical Kit (MSK) was provided in a sterile folded soft pack configuration in the stowed configuration. It could be deployed on the cabin wall or floor using Velcro attachments without violating the sterile field (Figure III). It was made of Nomex with stiffeners in all side panels to allow for shape maintenance in both the stowed and deployed configurations. All supply pockets opened towards a central sterile work field to facilitate the maintenance of sterile technique. Restraint was by supply pockets with Velcro fasteners, a magnetic pad for ferrous

instruments, elastic straps, and Velcro. Trash was disposed of using plastic lined pockets for wet biological trash and dry trash, flypaper areas (activated by peeling) for suture ends, and a Styrofoam block for sharp items such as blades and needles. The Styrofoam block was enclosed in a clear plastic case to guard against accidental dislodgment. The plastic case had a wide lid for easy access. Instruments were on the left panel for easy access with the right hand (Table I) and supplies (4 x 4's and suture) were on the right hand for easy access with the left hand. All supply pockets were labeled both vertically and horizontally and were also color-coded. The MSK measured 26 cm x 22 cm in the closed configuration and 65 cm x 54 cm when deployed. It weighed 0.95 kg with supplies in place.

The Surgical Restraint Scrub Suit (SRSS) was a sterile garment made of Nomex that was donned by the operator at the beginning of the procedure (Figure IV). All instruments, supplies and restraint mechanisms were on the chest area of the garment in a layout and design similar to the MSK. Trash disposal and sharp

disposal utilized the same techniques as the MSK. Labeling was also the same as the MSK with horizontal and vertical labels and color-coded pocket straps. It was initially provided in a folded up configuration with the sterile fields protected on the inside and weighed 1.5 kg. After it was donned the chest area became the working sterile field. Instruments were on the left side so that they could be accessed easily by the right hand.

The Surgical Tray (ST) was stored in its deployed state and therefore required greater volume for storage than the MSK or the SRSS. Supplies and instruments were arranged and restrained in a manner similar to the MSK and the SRSS. A more accessible restraint method using elastic bands instead of pockets for supplies was utilized. The surgical tray used a separate bag not as a part of the tray for trash disposal. The Styrofoam block was not enclosed in a plastic case on the ST as it was on the MSK and the SRSS. It was 40 cm X 40 cm and weighed 1.1 kg. The rigidity of the ST was obtained by a light weight aluminum backing that was canted 30 degrees up in the middle of the tray to decrease reach and

improve visibility of the portion of the tray most distant from the operator (Figure V). The rigidity of the tray allowed it to be deployed on the patient restraint system immediately next to the operative site in an attempt to improve ergonomics and sterile technique maintenance.

Sterile technique was used in all procedures and the feasibility of each method subjectively evaluated by clinically experienced surgeons.

Results

All methods worked well and the procedures were not much more difficult to perform in 0-g than in the 1-g environment.

Discipline was required to practice restraint procedures in 0-g and this did require all procedures to be approximately 50 % longer in 0-g than in 1-g. Any instrument or supplies that were accessed had to be re-secured back on the MSK, the SRSS, or the ST if not

being immediately used (in hand). Trash had to be disposed of in the trash pockets. Suture ends that were cut after tying surgical knots were disposed of in the flypaper areas and would not be allowed to float off. Sharp items (blades and needles) had to be carefully secured in the plastic encased Styrofoam block for obvious safety reasons. The enclosure of the Styrofoam block in the plastic case with a wide lid for access on the MSK and the SRSS ensured that the sharp items were not accidentally dislodged and become floating objects.

The MSK and the SRSS could be stored in a low volume configuration with protection of their sterile interiors. The ST had poor storability as it was rigid and required additional packaging to protect its sterility. It was also more difficult to deploy the ST without contamination.

All of these tested methods increased the ease of being able to maintain sterility in the 0-g environment as motions necessary to access instruments and supplies were minimized and were able to be kept close to the operative site. The placement of the MSK on

the cabin wall or floor in relation to the operator was critical to take advantage of this (usually just to the right of the operator). A platform closer to the operative site would have been preferable so as to transform the MSK into a surgical tray similar to that found in a conventional operating room. In this regard, the SRSS had an advantage over the MSK as the supplies were closer to the operative site. The rigid ST could be deployed immediately adjacent to the operative site and was therefore found to have the best ergonomics and the greatest ease of maintaining the sterile field.

Restraint and instrument supplies were accomplished by several techniques – magnetic pad, pockets, elastic straps, Velcro, flypaper areas, and the Styrofoam block for sharp items. Having a variety of techniques was found to be important and increased the flexibility of restraining supplies. Only if the operator became hurried and undisciplined in following restraint procedures did objects become unsecured to float away and become contaminated. As operators became experienced with working in the 0-g

environment this occurred less frequently. The magnetic pad worked well in 0-g but not in the 2-g pullout environment that is peculiar to parabolic flight. The elastic bands on the ST made it easier to access supplies as compared to the supply pockets on the MSK and the SSRS.

The ability to dispose of trash items was found important to efficiently perform a surgical procedure in 0-g. Wet biological trash and dry trash were easily placed in the plastic lined pockets, suture ends on flypaper areas and sharp items in the plastic box encasing the Styrofoam block.

All instruments and supplies necessary for these minor surgical procedures were well organized in a systematic way and could easily and quickly be located and accessed. Accessibility was not difficult although restraint methods such as Velcro straps on pocket items necessary to keep instruments and supplies secure did make the procedure slower than in 1-g. Accessibility on the SRSS was not as good as on the MSK and the ST in that it was

more difficult to visualize the items and access them due to their location on the chest area of the operator.

Discussion

Instruments, surgical supplies and hardware restraint is critically important in microgravity in order to be able to perform even a minor surgical procedure in a conventional and efficient manner. A system of disposal of trash (both biological and dry) as well as the securing of disposed sharp items in a safe manner is also a critical necessity. Instrument restraint also has to allow for the organization of supplies and the ability to maintain sterile technique (10,11,12).

Ergonomical considerations are very important to increasing the ease of performing any surgical procedure. The efficiency and success of the surgical procedure is increased by minimizing operator movements and reach requirements, limiting the necessity

of changing body positions during the procedure, and increasing coordination by optimizing the relationship of the operator to the surgical supplies and instruments. Improving the visualization of supplies, making instrument access easier, and decreasing reach distances are all methods that need to be designed into the surgical instrument restraint system both in 0-g and 1-g. Other design considerations are the ability to store in a low volume configuration with sterility protection, deployment ease, being able to maintain the sterile field, organizing supplies in a logical manner, limiting the amount of supply processing prior to use, and decreasing trash generation. The 0-g environment requires greater emphasis on minimizing logistics and perfecting ergonomics as compared to the 1-g environment. In the conventional 1-g operating room, it is often considered desirable to have as much logistics as possible as there are no volume constraints. Trash generation is also of no consequence. As there are often assistants present to handle logistics and supplies, ergonomics are also considered to be less important although it would increase operator

efficiency and coordination. Poor ergonomics in 0-g will quickly translate into inefficiency and procedural difficulty. By emphasizing more exacting ergonomical design, 0-g investigations can lead to a better understanding of ergonomics in the conventional 1-g operating room.

Self-contained kits have the advantage of logistical efficiency in that all of the supplies needed are readily and rapidly accessible and already in an organized location. Having all the supplies that are needed immediately available is a tremendous advantage of pre-packaged surgical kits as compared to pulling supplies from individual locations according to a checklist and then opening multiple sterile packages one at a time. This process can take a large amount of time and can require additional personnel. In addition, storage volume is increased and more trash is generated. The disadvantage of a pre-packaged surgical kit is that if only one item in the kit is needed then the whole kit is sacrificed when that item is accessed, as it can then no longer be considered sterile. This lack of flexibility can be overcome if it is determined that the

incidence of requiring a specific item in a kit during a long duration spaceflight is low enough to accept the risk of that item being present only in the kit. At the same time, several of the most likely to be accessed items could be present not only in the kit, but also separately individually packaged.

A more advanced concept is that analogous to the convention operating room in 1-g. A sterile surgical tray is present with items immediately accessible for the procedure (similar to the MSK and the ST). There is also a sterile back table with items that may possibly be needed or needed later in the procedure. A non-sterile kit with individually wrapped sterile items could serve this purpose. This could also have items that are most likely to be used individually in other procedures that could be accessed without compromising the entire kit.

The ST took the best advantage of ergonomics, as it was immediately adjacent to the operative site. However, the rigid surface precluded good storability. Storage volume is higher and protection of the sterile field during deployment is more difficult.

The SRSS has several inherent deficiencies that make it less desirable than the MSK or the ST. The instruments and supplies were not as easily visualized or accessible. There was less flexibility in that once the suit was donned, the operator could not leave the operative site. On the other hand, maintenance of sterile technique was easier in the SRSS as compared to the MSK since it was closer to the operative site and required less operator movement away from the operative field to access supplies. This could be improved in the MSK if it were deployed in a similar fashion to the ST immediately adjacent to the operative site by a rigid portion of the patient restraint system.

However, creating a surgical kit is just one part of increasing the on-board surgical capabilities in space. There are many other issues that must be addressed to allow for the feasibility to perform surgical procedures. Patient and operator restraints must be created that are easily deployable and allow flexibility for positioning the patient and the operator. In the confines of a spacecraft it will be difficult to rapidly create a sterile surgical area

in an emergency. Training will be one of the more complex issues to address. It is difficult to justify having a surgically capable crew medical officer present unless the likelihood of his utilization in-flight is apparent. Even if the crew medical officer has surgical experience, it could be months before a surgical procedure is necessary. Training procedures will need to be developed for training on the ground, in parabolic weightlessness, and to maintain proficiency in-flight. In addition, specialized procedures that lend themselves to increasing the feasibility of performing a surgical procedure in weightlessness, such as minimally invasive surgical techniques, are being investigated in parabolic flight.

Conclusion

The Minor Surgical Kit has several design features that facilitate the performance of a surgical procedure in weightlessness in a more efficient manner than previous methods. It allows for

instrument logistics, organization, accessibility and restraint, maintenance of the sterile field, and the disposal of trash and sharp items. It has excellent storage characteristics and is easily deployed without endangering sterility. Its main disadvantage, deployment on a cabin wall too far from the operative site, can be improved by providing a rigid surface closer to the operation on the patient restraint system.

In the future, further parabolic flight weightless simulations will be needed to verify the feasibility of more complex surgical procedures and hardware. As manned spaceflight continues to expand to longer duration missions, the potential for medical scenarios requiring surgical intervention will also increase. In addition to manifesting more surgical hardware and training more surgically capable crew medical officers, we will need more sophisticated instrument and supply restraint methods than are presently available to accommodate this increased capability.

References

1. Billica RD, Simmons SC, Mathes KL, McKinley BA, Chuang CC, Wear ML, Hamm PB. Perception of Medical Risk of Spaceflight. *Aviat Space Environ Med* V67 (5):467-473. (1996).
2. Campbell MR. Surgical Care in Space. *Aviat Space Envir Med.* 70:181-184. (1999).
3. Wilken DD. Significant Medical Experiences Aboard Polaris Submarines: A Review of 360 Patrols During the Period 1963-1967. U.S. Naval Submarine Medical Center Report #560. Groton, Conn. 1969.

4. Tansley WA, Wilson, JM Schaefer KE.
Analysis of Health Data from 10 years of
Polaris Submarine Patrols. Undersea
Biomedical Res. Submarine Supp. 1979; S217-
S246.
5. Musgrave S. Surgical Aspects of Space Flight.
Surg. Annual 1976; Vol. 8:1.
6. Barratt, M. Medical Support for the
International Space Station. Aviat Space
Environ Med 70:155-161. (1998).
7. Campbell MR, Billica RD, Johnston SL.
Animal Surgery in Microgravity. Aviat Space
Environ Me 1993; 64:58-62.

8. Campbell MR, Billica RD, Johnston SL.
Surgical Bleeding in Microgravity. Surg
Gynec & Ob. 1993; 177:121-125.
9. Campbell MR, Billica RD, Jennings R,
Johnston S. Laparoscopic Surgery in
Weightlessness. Surg Endosc 10:111.1996.
10. Campbell MR, Billica RD. A Review of
Microgravity Surgical Investigations. Aviat.
Space Environ. Med. 1992; 62:524-528.
11. McCuaig K, Houtchens B. Management of
Trauma and Emergency Surgery in Space. J
Trauma. 33(4).610-625. (1992).

12. Kirkpatrick A, Campbell M, Novinkov O,
Goncharov I, Kovachevich I. Blunt Trauma
and Operative Care in Microgravity. Surg Gyn
Ob. 184 (5), 441-453. (1997).

Tables

Table I. Minor Surgical Kit Supply List.

Left surgical instrument panel

- Adson tissue forceps
- Small hemostats (2)
- Small Metzenbaum scissors
- Small needle holder
- Scapel
- Large hemostats (2)
- Right angle clamp

Right supply panel

- 4 X 4 sponges
- #1 suture pocket - 2-0 Vicryl on SH needle
- #2 suture pocket - 2-0 Nylon on CT needle
- Scapel blade (#10)
- Betadine swabs
- Prefilled 10 cc syringe of 2% Xylocaine with a
22 ga needle

Lower Supply/Trash panel

- Allows for initial stowage of first items to be
accessed (gloves and Vidrape)
- Then converts to trash stowage pocket (is plastic
lined for wet trash)
- Has flypaper area (peel off) for suture end discard

Central sterile field work area

- Velcro restraint area
- Magnetic pad area
- Sharps discard area (Styrofoam block with plastic
cover for additional protection)

Figures

Figure I.. The Surgical Supply Subpack also called the Surgical Instrument Assembly located in the Shuttle Orbital Medical System (SOMS) on board the Shuttle and in the Ambulatory Medical Pack (AMP) on board the International Space Station.

Figure II. The Emergency Surgical Subpack located in the Advanced Life Support Pack (ALSP) on board the International Space Station.

Figure III. The Minor Surgical Kit evaluated in parabolic flight.

Figure IV. The Surgical Restraint Scrub Suit
evaluated in parabolic flight.

Figure V. The Surgical Tray evaluated in parabolic
flight.